Report Plexos Project

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Abstract

1 Introduction

In this project were modeling and analyzing a highly simplified version of the Nordic power system and its connection to continental Europe. The system consists of three nodes representing Norway, Sweden and Germany linked with transmission lines. Norway produces energy through two hydro plants, a wind power plant, and a gas plant. The annual demand in Norway is roughly 130 TWh. The annual demand in Germany is almost 550TWh covered with several coal, nuclear, gas and oil plants and two renewable consisting of solar and wind. Sweden has next to nuclear, coal, gas, oil, hydro and wind, a biopower plant to cover the demand of 145TWh. In a first part the main goal is to find the optimal operation plan for this system for the year 2014 and detect the impact of different weather conditions. In a second part the objective is to conduct Expansion planning with given investment options and evaluate the optimal approach. This report should clarify the influence of different weather conditions on an operation plan. The report also state two possible solutions for the expansion plan using the green certificate and the emission tax approach. The report deliver an insight to what is built, when and where and what the effect on prices, emissions and capacities is.

2 Theory

2.1 Methods in present work

2.2 intermittent resource handling

2.3 reservoir hydro handling

Calculating with reservoir hydro is not as straight forward as with thermal units because there are no fuel prices which could be use for an optimization. Even if the water to a reservoir comes for free, does not mean that it does not have a value. The quantity of water is limited. Often there are environmental regulations that need to be considered. For example fixed residual water flows. To calculate with a reservoir it is important to have information about the reservoir size (maximum and minimum capacities) and inflow patterns. The question with hydro reservoirs is should we use the water right away or store it for later. If there is a large inflow, spillage can occur and the economic value will be zero. If the Inflow is very low, there is the risk of cant produce enough energy to cover the demand. It is very difficult to forecast the conditions. In this project we work with different inflow scenarios in order to identify the influence of different reservoir levels to the optimal operation plan.

2.4 region exchange

Power is a vital element that supports our modern lives. Power has to be available to any time at day and night. To cover the increasing demand and create a stable system transmission of power between countries has become more and more common.

2.4.1 Advantages

The focus of power exchange is trade. Economic theory states that a perfectly free market is equal to the optimal use of resources. A common power market introduces free competition and increases stability. Available power capacities can be used more efficiently due to a larger region. Another advantage is that power can be produced on the most economic worthwhile region. For example is a wind power plant built in an offshore region better placed than in a region with lack of wind. This means that more power from different sources like hydro, thermal, wind and solar enters the grid. The market is not depending on conditions like rain, wind or sun and the prices remain more easily stable due to a "liquid" market. The price of power is determined according to supply and demand. A larger area has the advantage of a more stable supply and demand. This affects the price in a positive way.

2.4.2 Disadvantages

If there is a unexpected peak demand or supply shortage in the common market, prices can get extremely volatile. The characteristics of such a price risk are highly dependent on the fundamentals of the market such as the mix of generation types. Another disadvantage is the risk of getting dependent on another country due to the fact that energy can be produced there cheaper. There is a risk of supply shortage if the political condition change.

2.5 investment initiatives for renewable sources

The support of renewable energy sources has in the latest years more and more become an international issue. Global warming has pointed out the need of international and national laws and regulations.

- International
  International laws and regulations try to follow the motto from the "Brundtland Commission": Think globally and act locally. On the international level, there are two key documents. First there is the Rio Declaration, a statement of 27 principles upon which nations agreed to base their actions in dealing with environmental issues. And Second there is the Kyoto Protocol, an international agreement which commits its parties to set binding emission reduction targets. These documents introduce several mechanisms how to stimulate increased investments from renewable.

- National (Norway)
  Norway introduced the Energy Act to follow up with its obligations. The Energy Act states that all production, conversion, transmission, sales, distribution and consumption of different energy forms shall be done in a "social rational way". Together with Sweden developed Norway a market-based power system.

- investment support
  One time financial support to cover part of the investment costs. The support is large enough to make the investment profitable. Some differences can be used for fine tuning, e.g. more support for wind power in areas with less wind.
  - advantages
    * possibility of finetuning
  - disadvantages
    * requires much capital at beginning
    * no incentive to roduce
    * limited security for investor
    * in case of fine tuning: much administration

- tendering
  Auction for a certain amount of capacity which shall be installed. Won by the offers requiring the lowest support. This initiative is also done as investment support, but with a tendering procedure. Providers are asked for support bids, the cheapest one gets the support.
  - advantages
    * competition between suppliers, therefore lower costs than investment support
  - disadvantages
    * same as investment support, but
    * less predictability
    * prone to corruption

- feed-in tariff
  A fixed price for feeded kWh is payed for a predefined period.
  - advantages
    * promotion of mid-term and long-term technologies
    * investment security for producer
  - disadvantages
    * possible risk of technology overfunding
- premium
  Like feed-in tariff, but instead of a fixed price an additional amount per kWh is paid to the producer.
  - advantages
    * market based
  - disadvantages
    * less certainty than feed-in tariff
- green certificates This is a nordic system for supporting renewables. Some amount of certified energy has to be bought from energy suppliers, otherwise they are penalized. The intention is to build as much renewables as possible in short time. From 2020 new renewables are not certified any more, so the possibility to get enough certified power decreases and the risk of getting penalized increases.
  - advantages
    * control of total amount of renewables
    * efficient market-based solution
  - disadvantages
    * less certainty than feed-in
    * complex
    * high administration costs

3 Analysis

3.1 MT Schedule

The medium term schedule is done for one year. Three different scenarios (low, normal, high inflow) to the reservoirs in Norway and Sweden are simulated. The different scenarios are described below.

3.1.1 normal inflow scenario

For this case a normal inflow scenario was chosen. The inflow accords to the average inflow in a year in Norway and Sweden.

optimal generation dispatch
The optimal generation dispatch for normal inflow for Germany can be seen in figure 1. The generation dispatch for swedish generation units can be seen in figure 2, the norwegian dispatch is shown in figure 3.

- Germany
  The nuclear power plants as well as the small coal power plant are running the whole year with full capacity for serving the base load. It can be obtained that in the winter is less solar power produced than in the summer, but more wind power is generated. The oil and small/medium gas generation units are hardly producing any power.

- Sweden
  The base load in Sweden is fully covered by nuclear and coal power. In summer some peak load is generated with small hydro, in winter the peak load is mainly covered with reservoir hydro. No power is produced with oil power plants, only small amount with gas generation.

- Norway
  In Norway more or less all power is produced by hydro power. In winter the power generation is mainly done with reservoir hydro, in summer about half of the produced energy is done with small hydro power. Some additional power is produced with wind generation, the installed gas power plant is producing no energy.

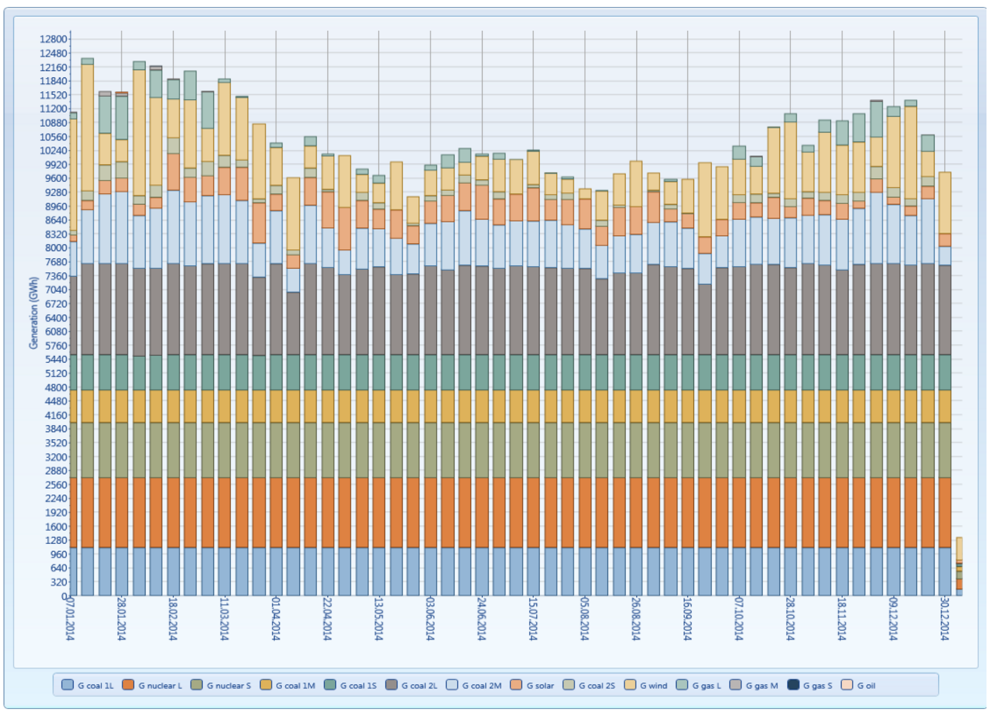


Figure 1: Optimal generation dispatch for Germany 2014 with normal inflow

transmission

The transmission between the three countries Norway, Sweden and Germany is shown in figure 4. It is done not considering the flow direction, but the amount of power. Here it can be seen that most power flows between May and October. In winter there is very low flow between Norway and Sweden. The most continuous flow exists between Norway and Germany.

emission

The total emissions for all countries together can be seen in figure 5. The emissions can be interpreted in following way:

- Norway: Due to the fact that most power installed is done with renewables (hydro power, wind power) and only some small amount of gas power, there are hardly and CO_2-emissions in Norway.

- Sweden: Some renewable energy and a large amount of nuclear power lead to small CO_2-emissions.

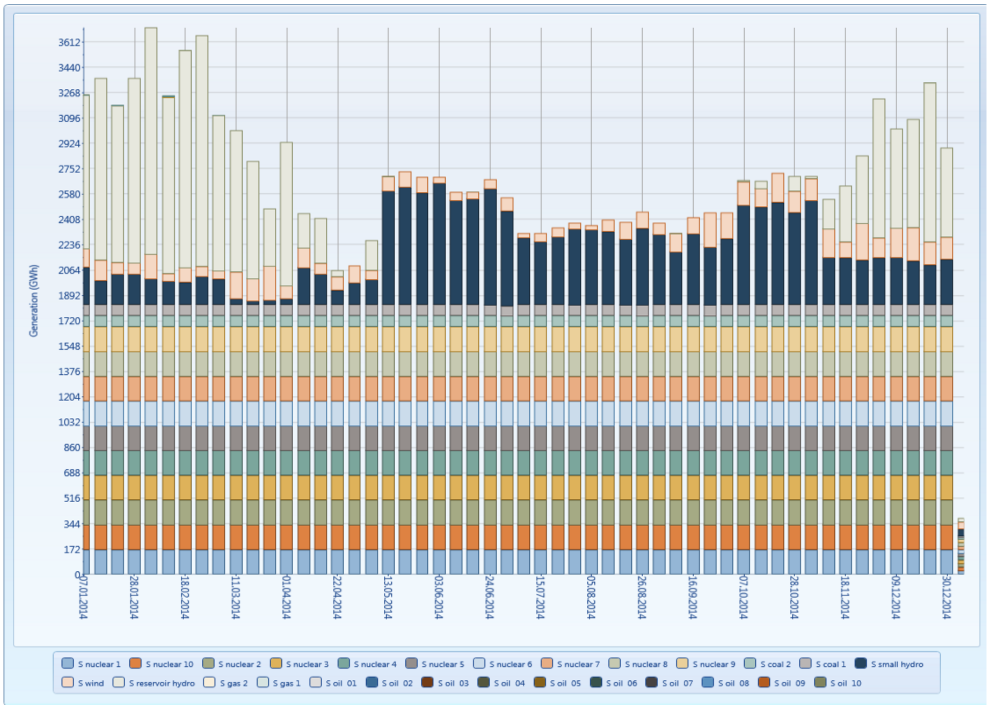


Figure 2: Optimal generation dispatch for Sweden 2014 with normal inflow

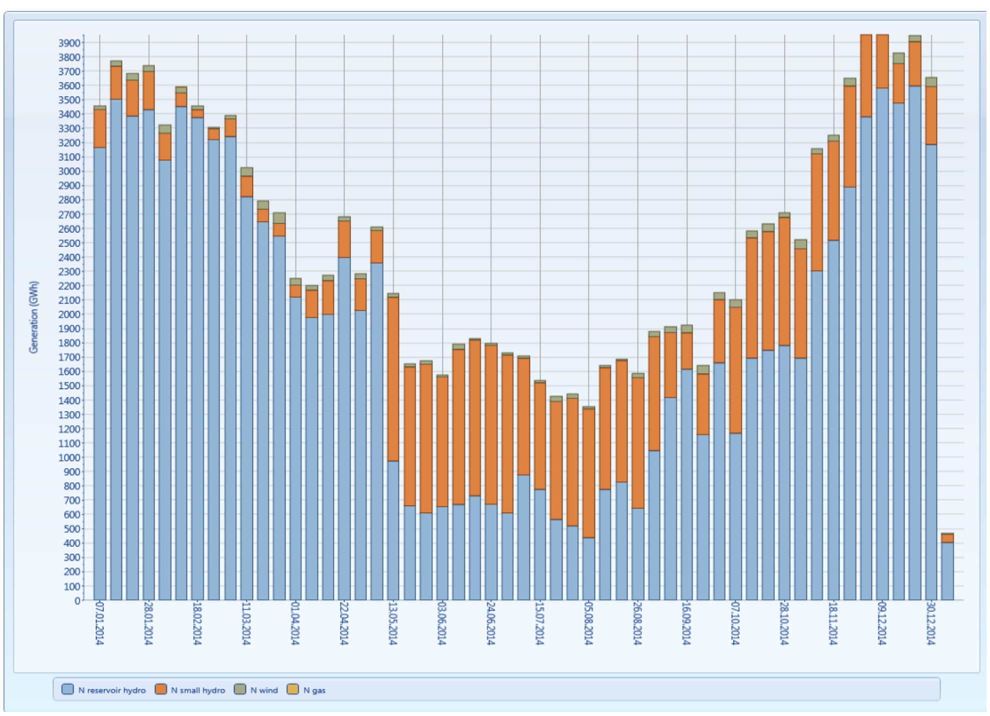


Figure 3: Optimal generation dispatch for Norway 2014 with normal inflow

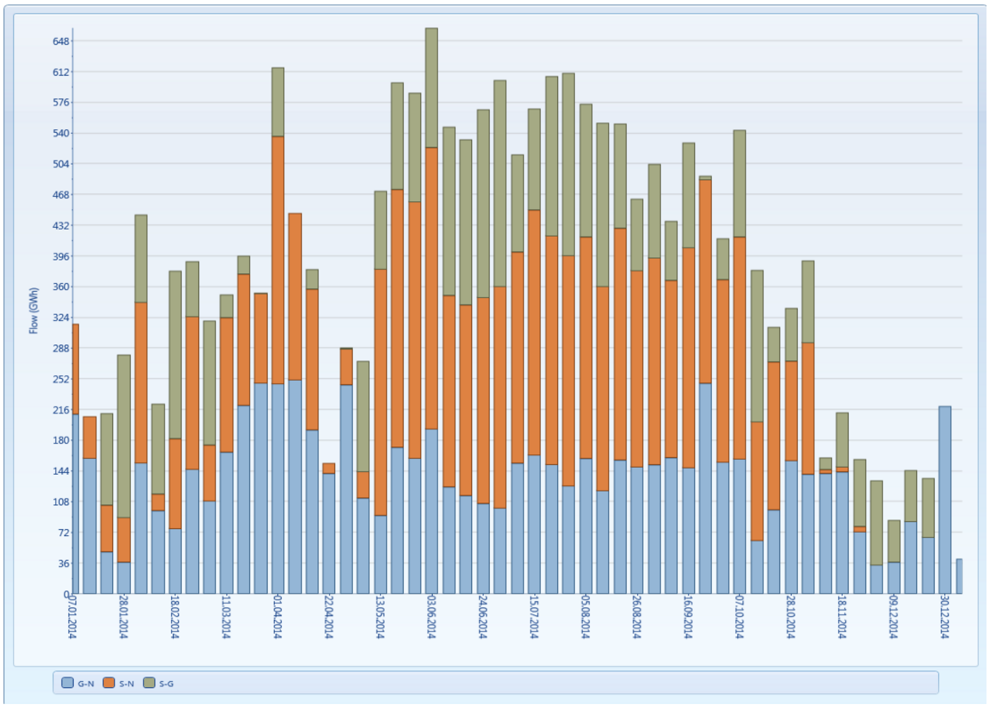


Figure 4: Transmission between N/W/S with normal inflow

- Germany: The biggest amount of the produced emissions are emitted from german power plants.

price

Energy prices for the different weaks of 2014 for the analyzed countries are shown in figure 6. In this graph it can be obtained that prices in Norway are the lowest because of the high amount of renewable energy. The energy prices in Germany are the highest because of some coal and gas power. Generally the prices during the summer are lower than in the heating season.

3.1.2 low inflow scenario

In this scenario a dry year with an inflow below the average was assumed.

optimal generation dispatch

The optimal generation dispatch is shown in figure 7 (Germany), figure 8 (Sweden) as well as figure 9 (Norway).

- Germany
  Due to the fact that there is no renewable energy in Germany, the simulated results remain mostly the same.

- Sweden
  Because of lower inflow the amount of energy produced with small hydro is lower than in average case. More energy is produced with reservoir hydro, but in dry years the production is a little bit lower than in the average simulation case.

- Norway
  Also in Norway the overall production decreases in the dry case. It can be obtained that

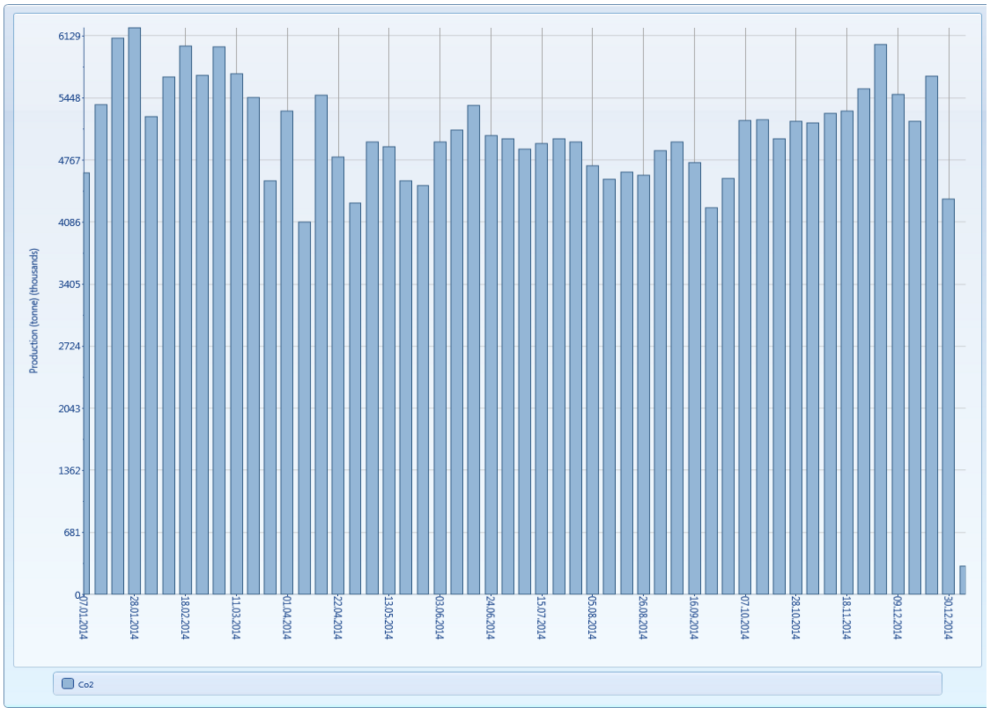


Figure 5: Total emissions for normal inflow 2014

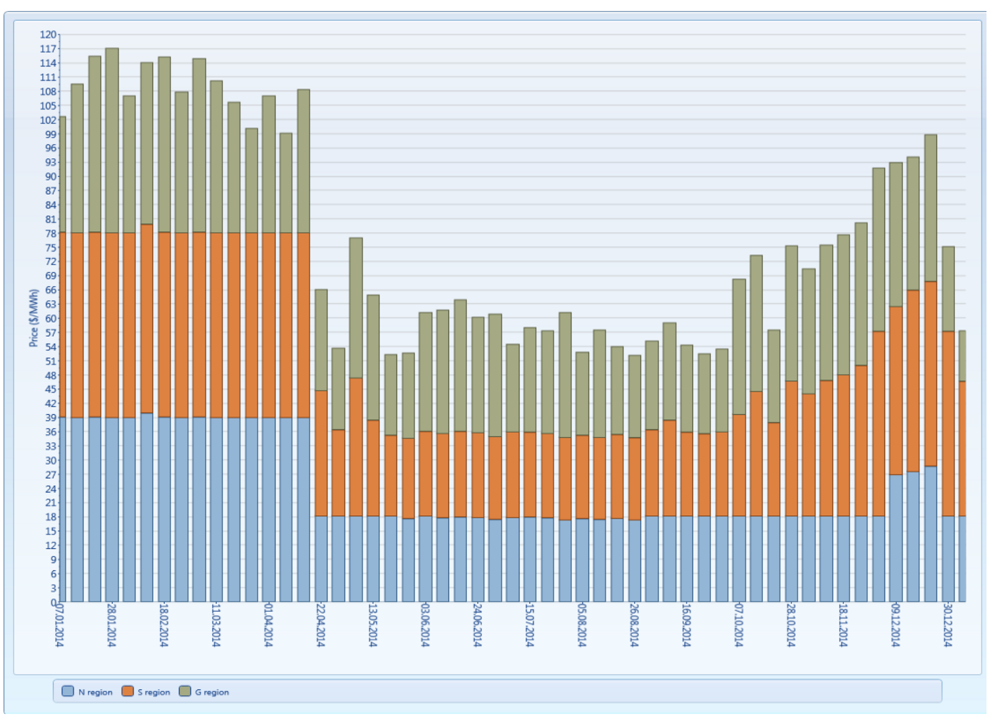


Figure 6: Calculcated prices with normal inflow

during the heating season the difference to the average inflow is not significant. Most power is produced with reservoir hydro units. In summer the production is mainly done with small hydro power, which is quite different to the average. In dry years some gas production is used during the whole period.

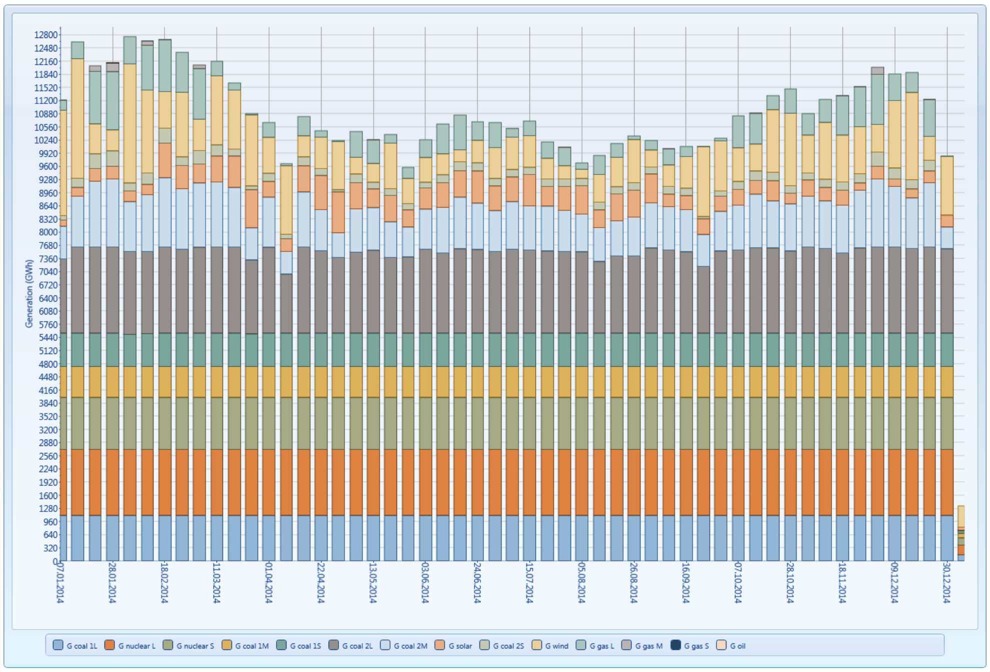


Figure 7: Optimal generation dispatch for Germany 2014 with low inflow

transmission

The power transmission on the powerlines between Norway, Sweden and Germany can be found in figure 10. In the dry inflow case it can be seen that the flow between Germany and Norway is almost constant over the whole year. Between Sweden and Germany is hardly any flow, while the energy transmission in summer increases very much.

emission

CO_2-emissions for the whole year 2014 are shown in figure 11. Compared to the average inflow scenario the emissions in Norway are a little bit higher. This is because more power is produced with the gas generation unit. The most emissions are generated in Germany.

price

The energy prices for a dry year 2014 are plotted in figure 12. Compared to the average inflow simulation, the prices are more constant over the year. The price level is higher due to lower renewable power production.

3.1.3 high inflow scenario

This scenario uses a very wet year 2014.

optimal generation dispatch

Optimal generation for Sweden is shown in figure 14. The generation dispatch for Norway can be seen in figure 15, the german production in figure 13.

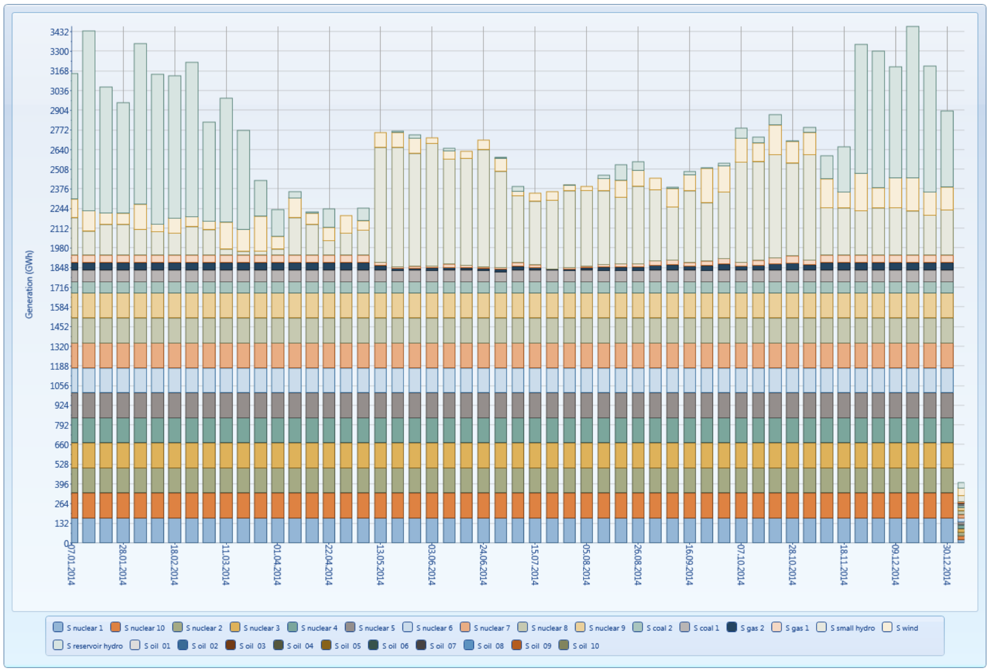


Figure 8: Optimal generation dispatch for Sweden 2014 with low inflow

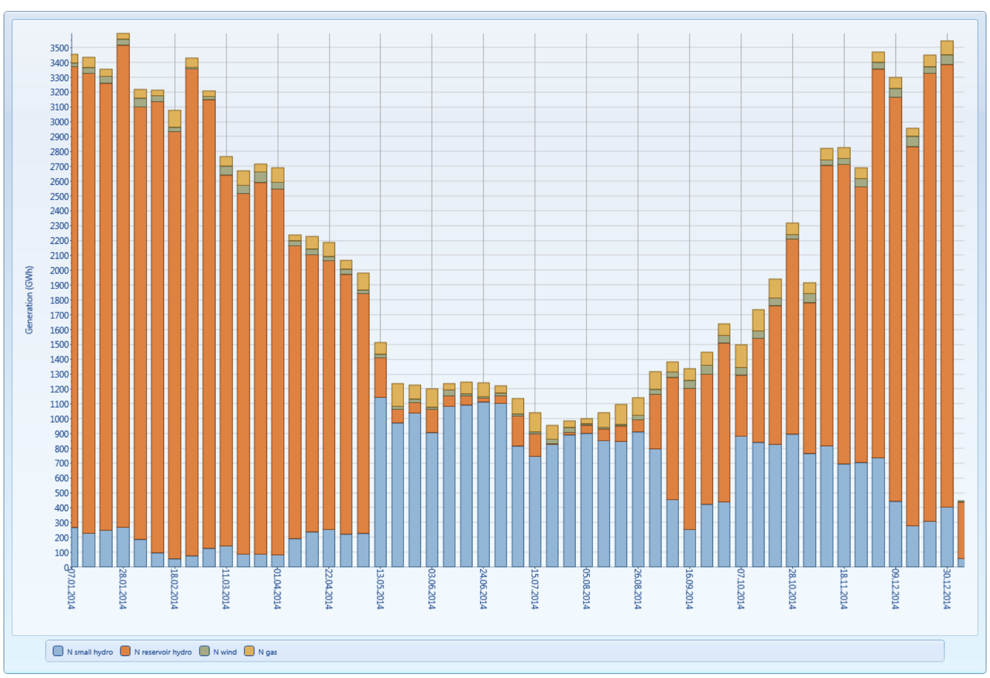


Figure 9: Optimal generation dispatch for Norway 2014 with low inflow

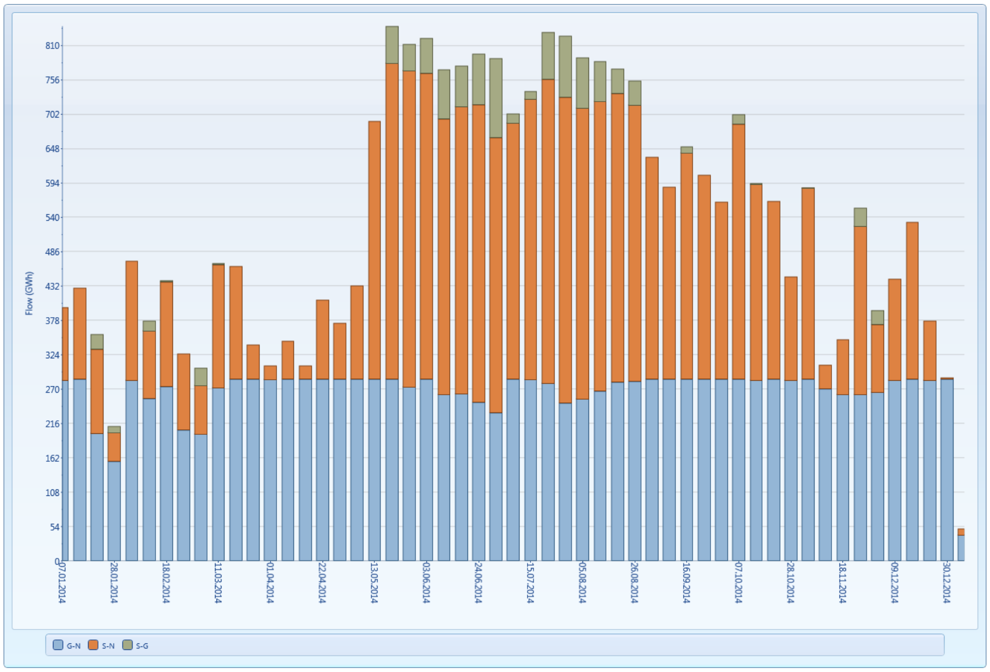


Figure 10: Transmission between N/W/S with low inflow

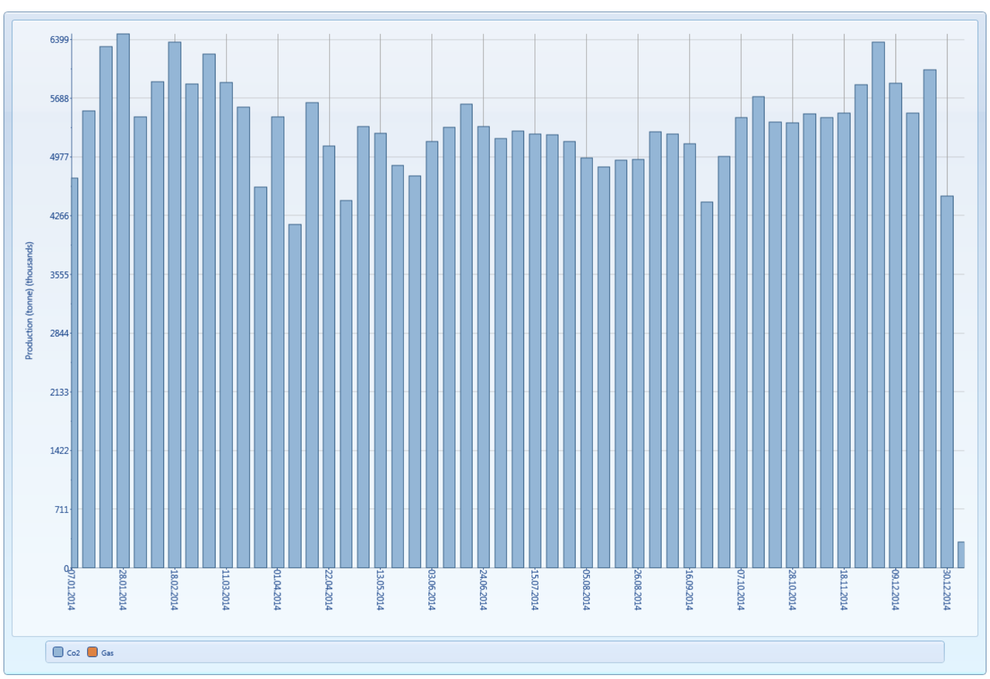


Figure 11: Total CO_2-emissions for low inflow 2014

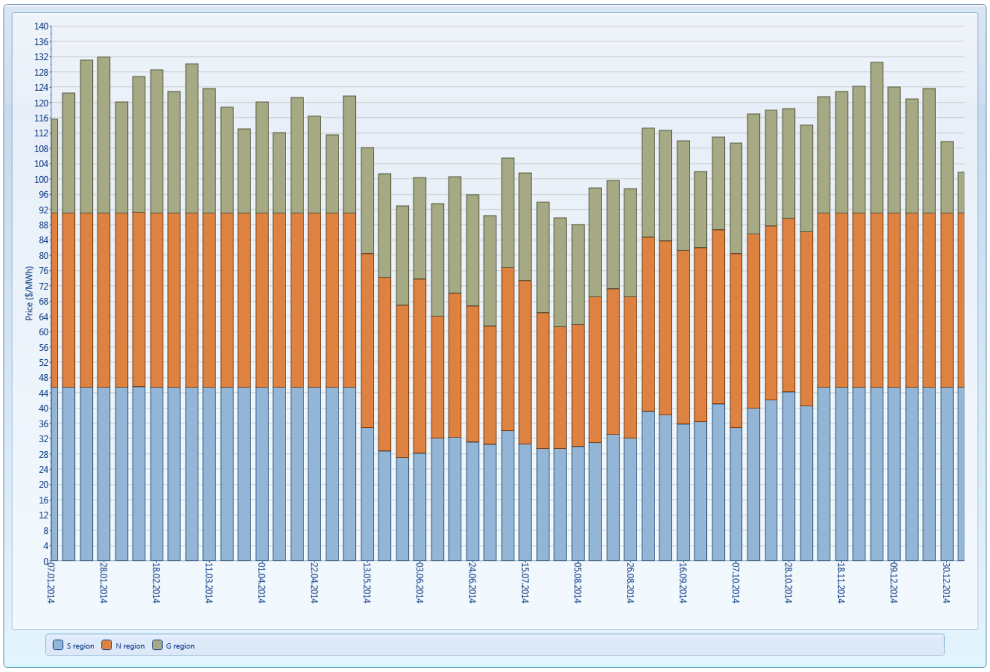


Figure 12: Calculcated prices with low inflow

- Germany
  As in the average in the average inflow scenario and the low inflow scenario, the generation dispatch in Germany does not change significant due to the fact that no renewable power is installed.

- Sweden
  With high inflow the base load is also covered with nuclear and coal power. It can be obtained that mostly all peak power is produced with renewable generation units. During the heating season the peak power is produced with reservoir hydro power, in summer most peak power is produced with small hydro generation. Some additional power is produced with wind power during whole year, oil and gas generation is hardly used.

- Norway
  All power is produced by renewables in the high inflow scenario. The generation dispatch is like the dispatch in the average scenario, but more power is produced.

transmission

The usage of the transmission lines between Sweden, Norway and Germany for high inflow into reservoirs is shown in figure 16. During heating season there is only transmission between Sweden and Germany, in the summer month there are huge transmissions between Sweden, Norway and Germany. Over the whole year there is very small transmission between Germany and Norway.

emission

Emissions of carbon dioxide by running thermal power plants for this scenario are plotted in figure 17. Due to the effect that Germany produces only non-renewable power the emissions decrease not very much in the high inflow scenario. They are a little bit smaller, so it can be said that some energy is transferred from renewable energy to Germany.

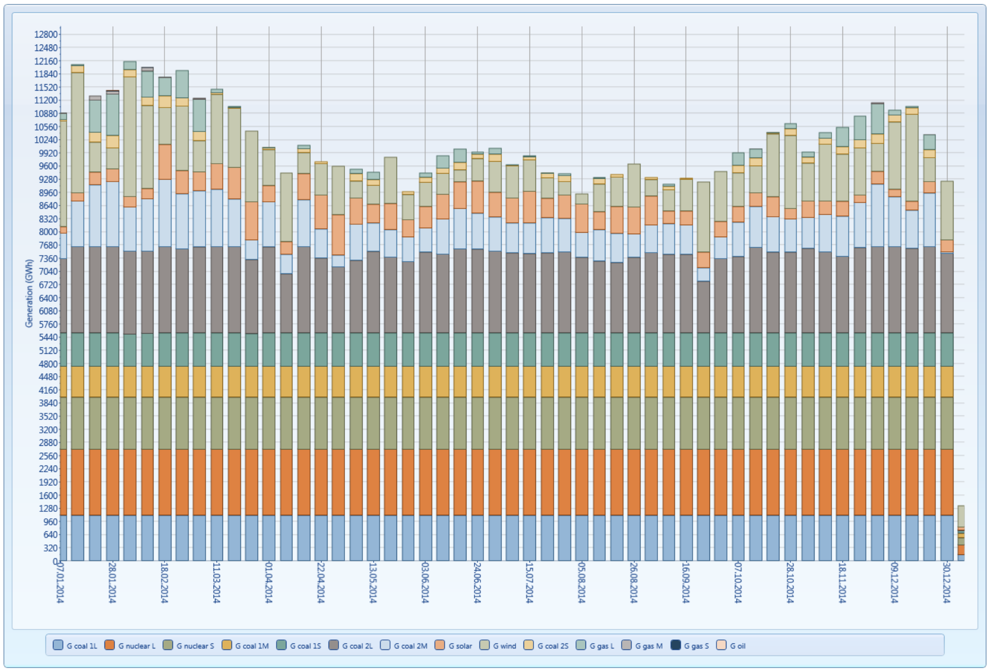


Figure 13: Optimal generation dispatch for Germany 2014 with high inflow

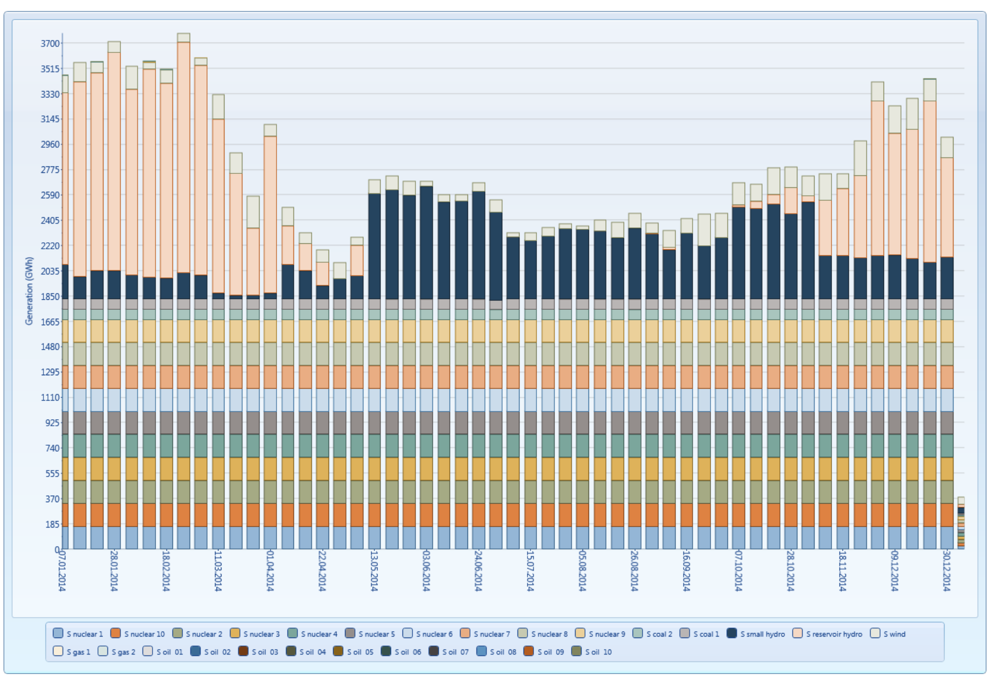


Figure 14: Optimal generation dispatch for Sweden 2014 with high inflow

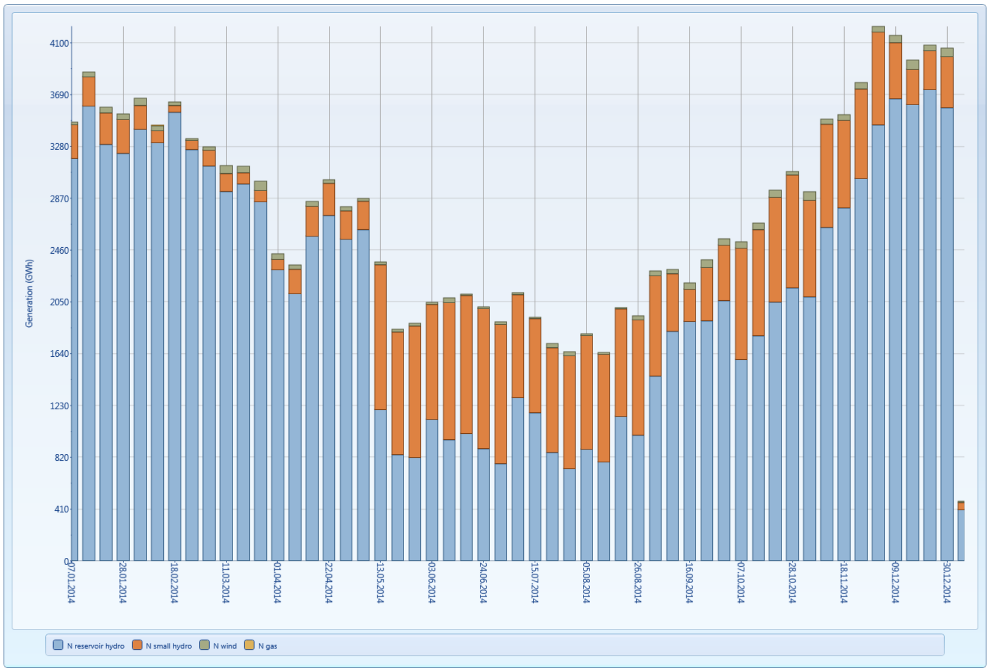


Figure 15: Optimal generation dispatch for Norway 2014 with high inflow

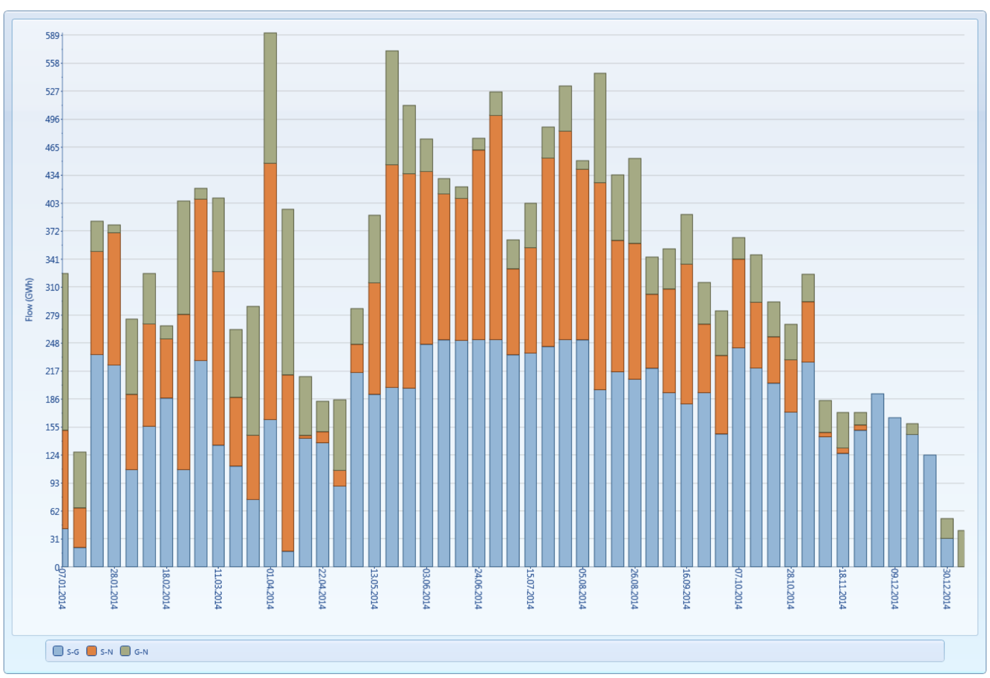


Figure 16: Transmission between N/W/S with high inflow

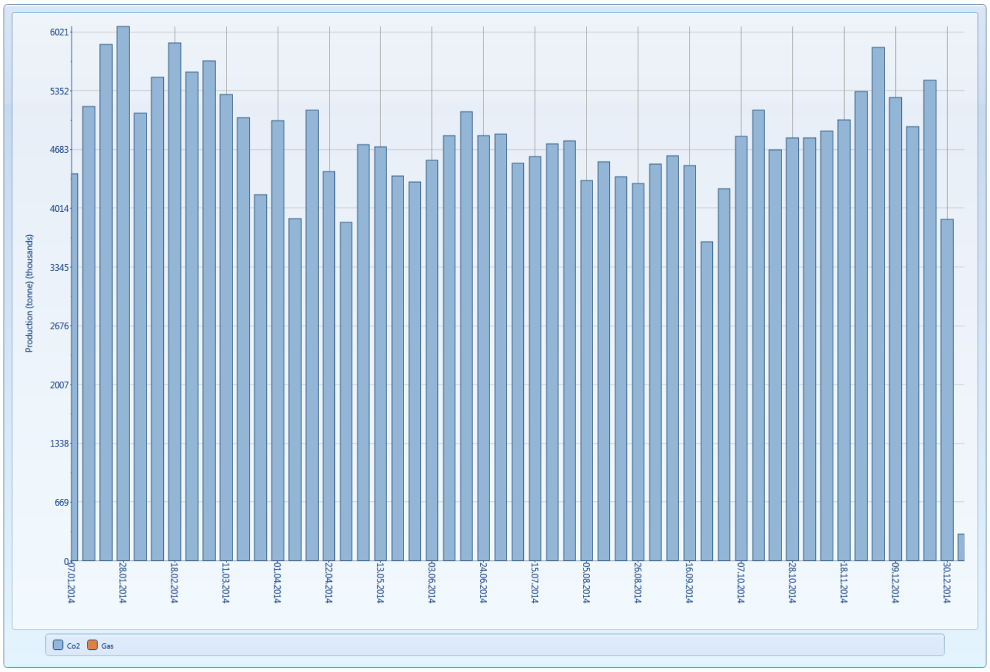


Figure 17: Total CO_2-emissions for high inflow 2014

price

The energy prices for a whole year 2014 with high inflow is shown in figure 18. The prices in Sweden are stable over whole the year, in Norway they are a little bit higher during the heating season. Over all the prices are lower the more inflow to the reservoirs is.

3.2 Expansion planning

The need of energy changes over time. So a simulation of future trends in energy production and transmission capacities is necessary for maximizing profit. In this case a decrease of energy need in Germany, a stable need in Sweden and small increases of power consumption in Norway is assumed. The simulation is done in three ways:

- ??????????
- green certificate system
- emission tax scheme.

As planning horizon a period of 20 years was taken, which is quite common for expansion planning simulations.

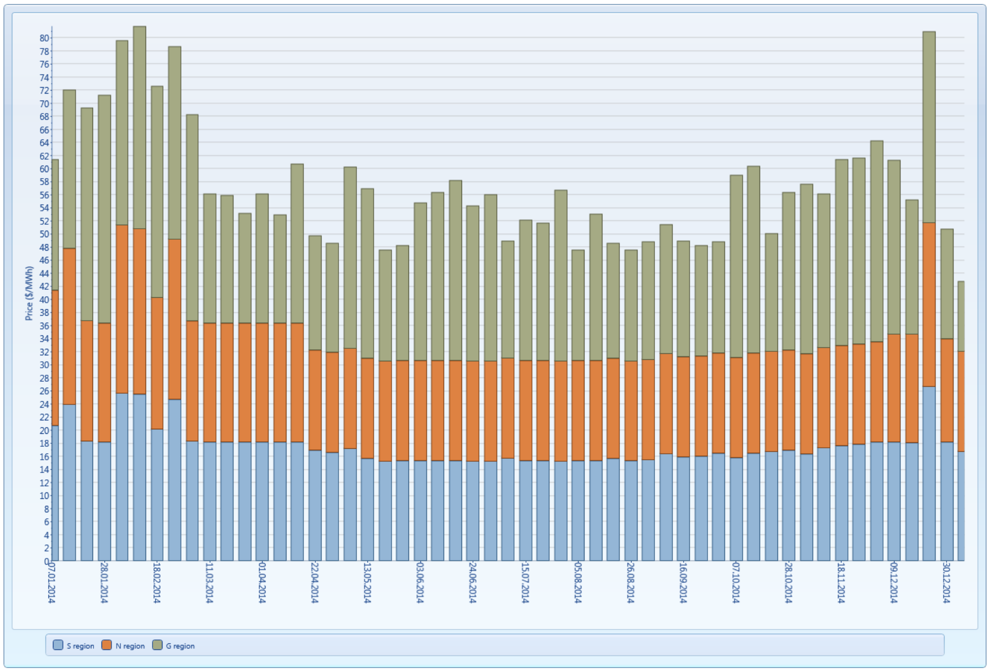


Figure 18: Calculcated prices with high inflow

4 Conclusion

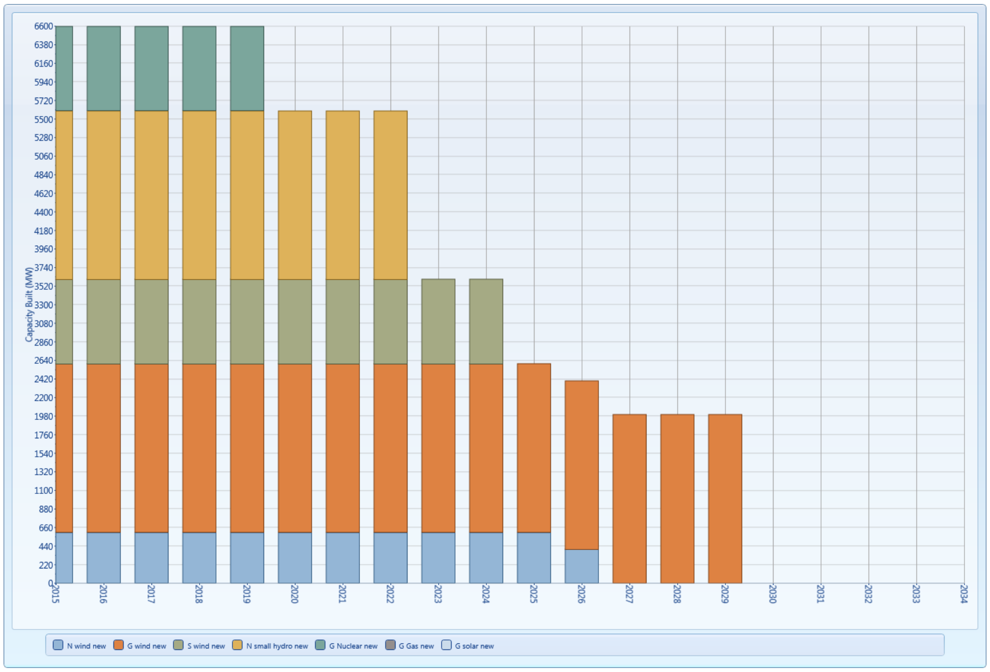


Figure 19:

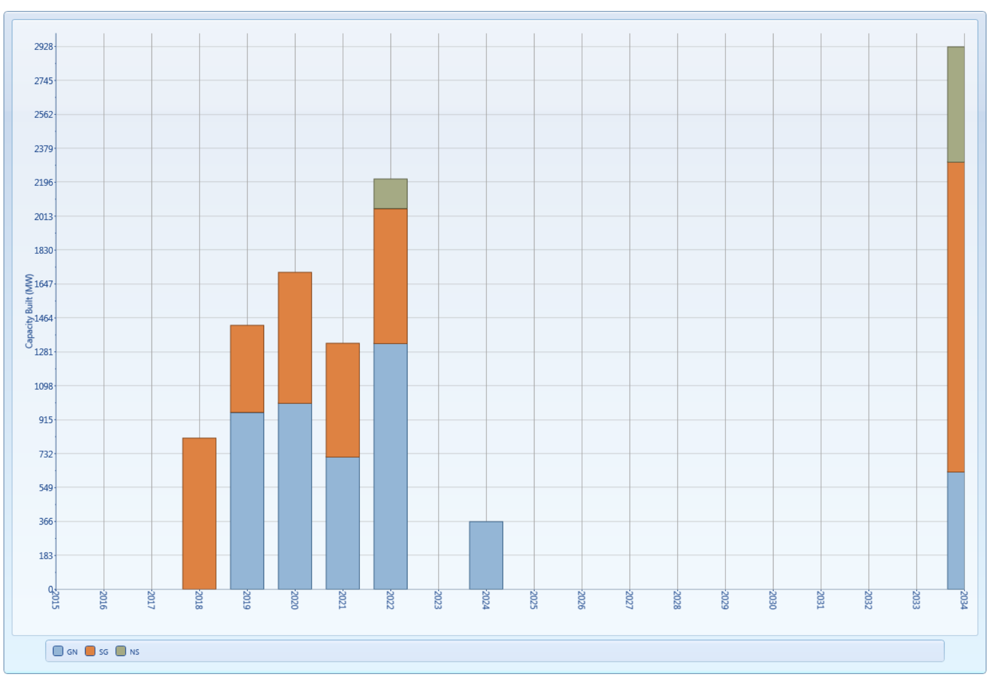


Figure 20:

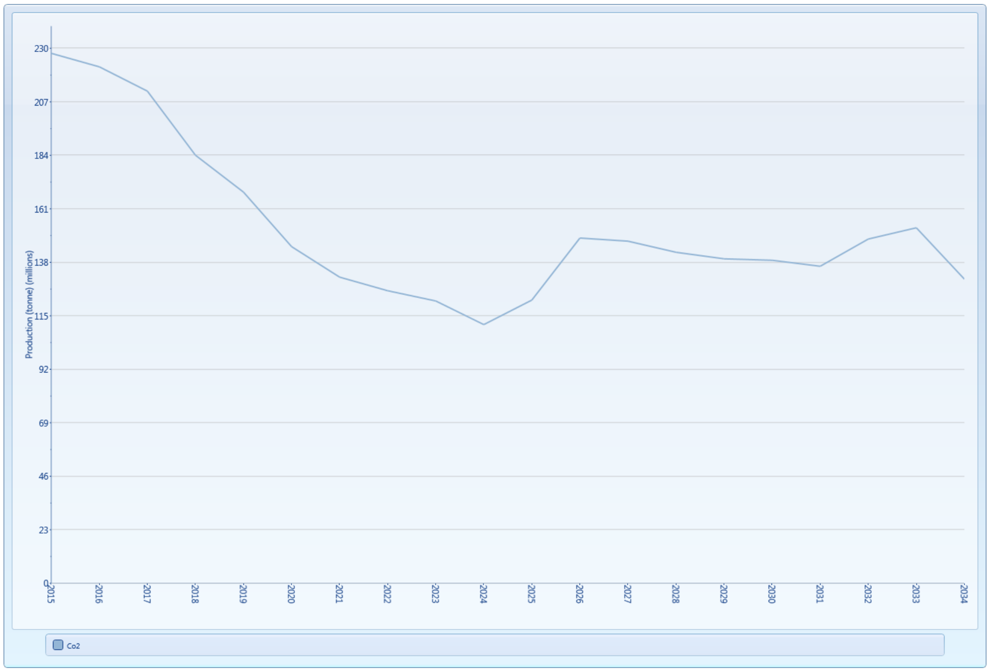
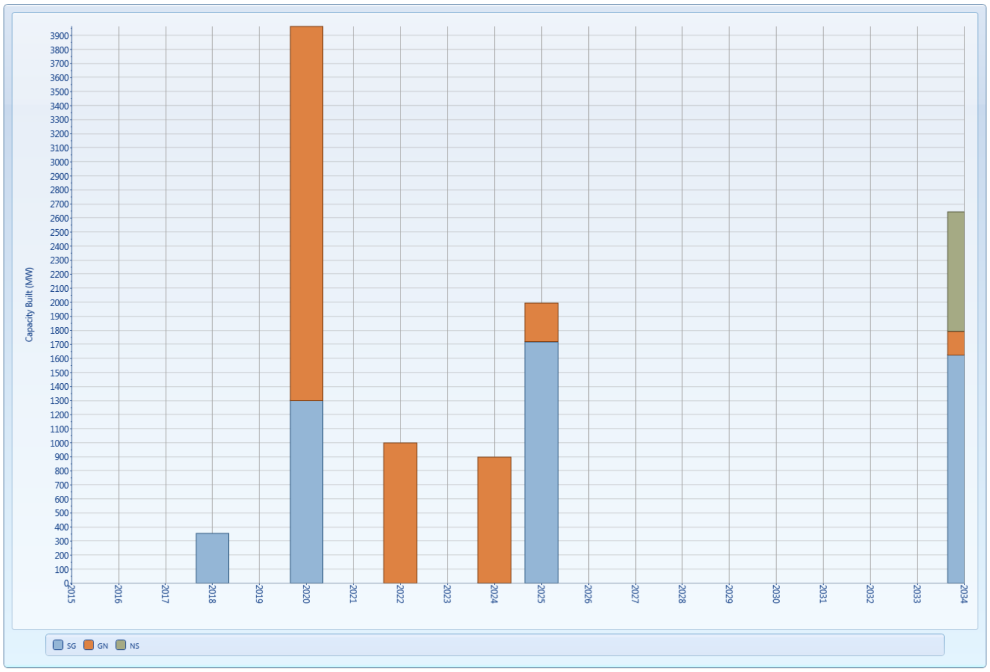


Figure 21:

Figure 22:



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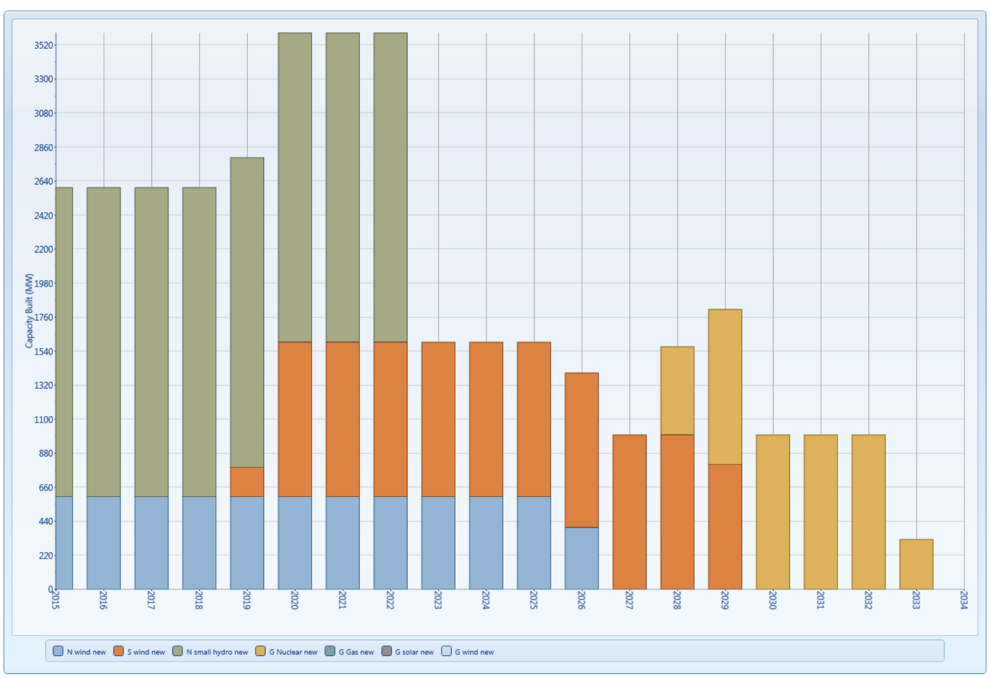

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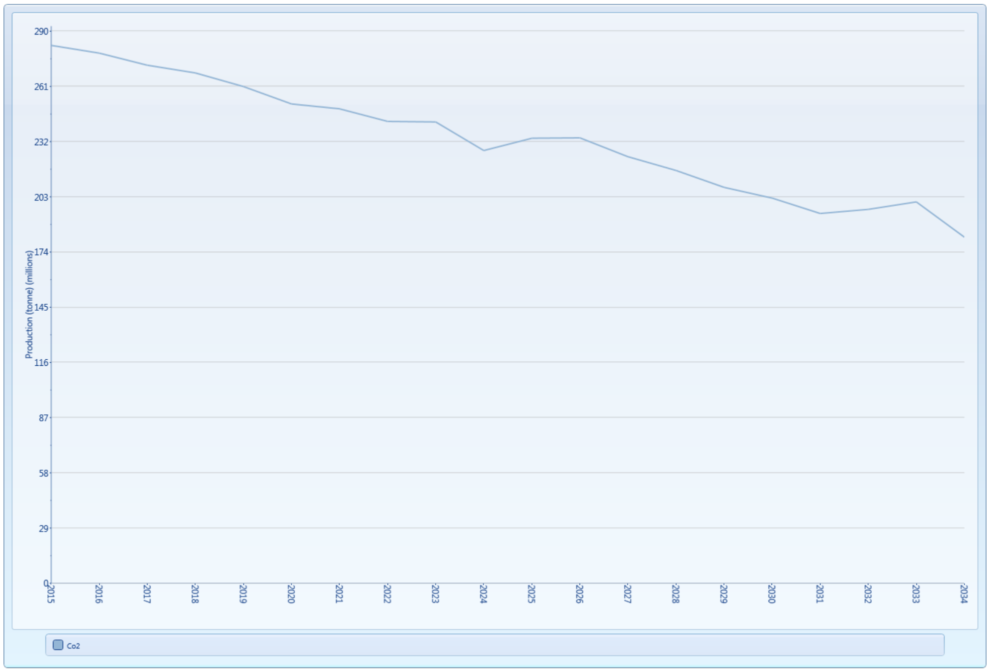

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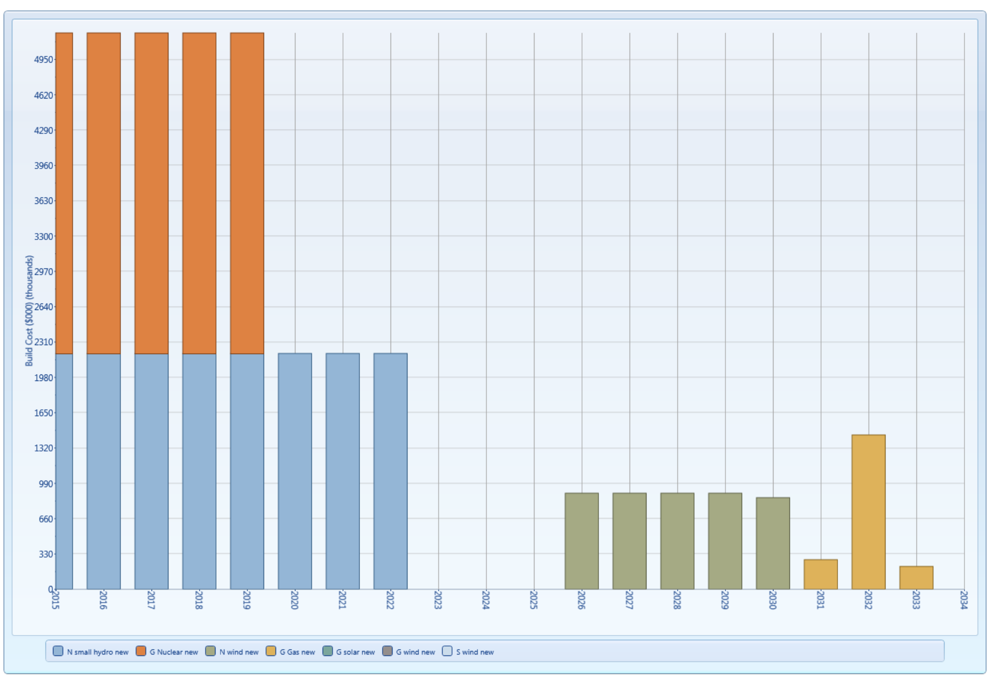

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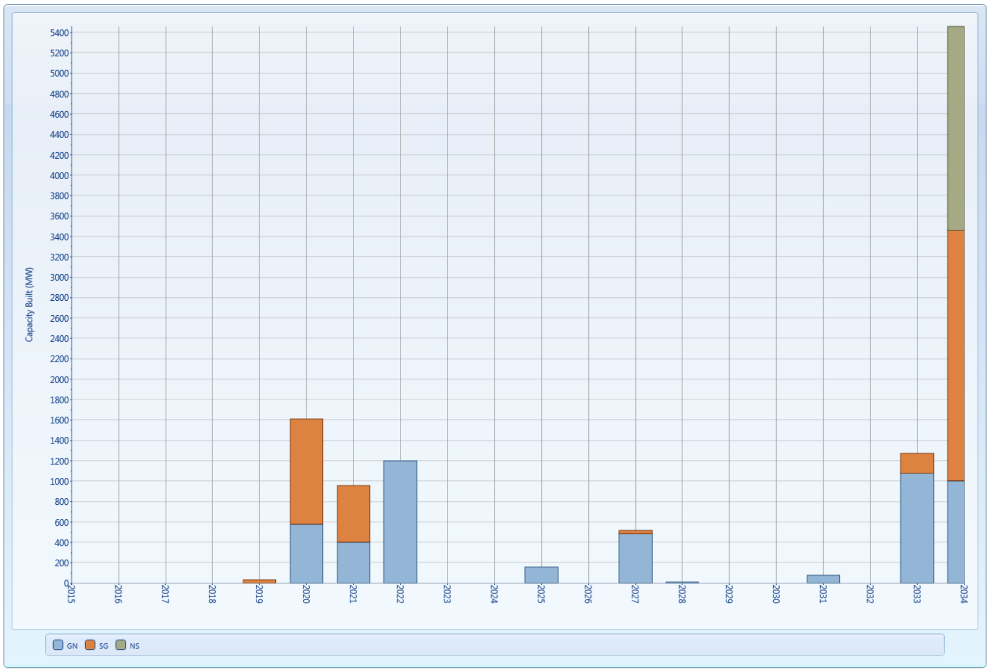
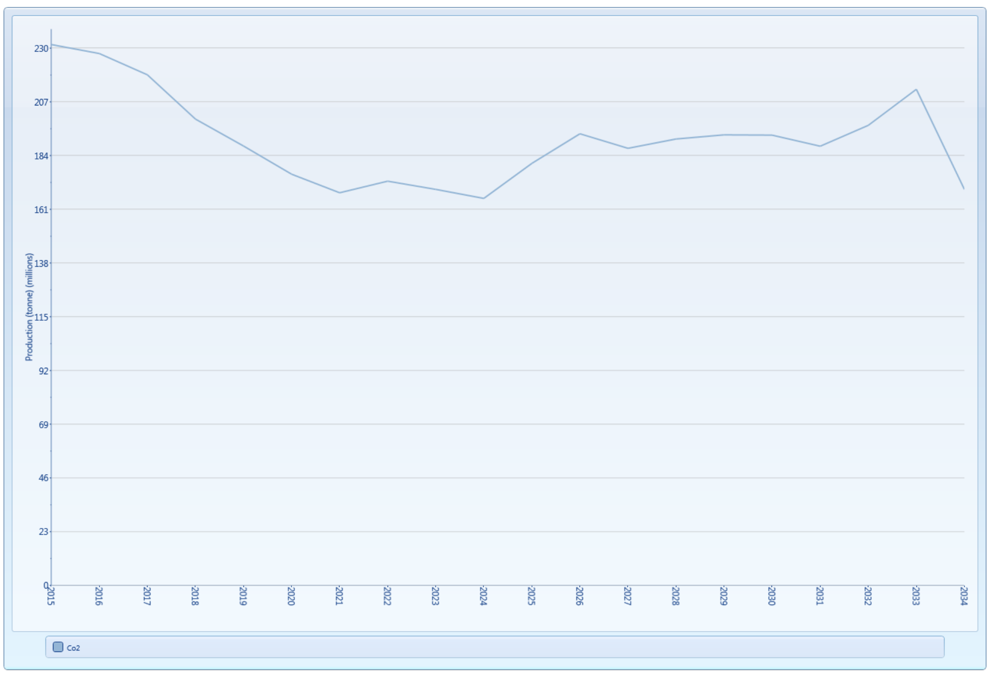


Figure 27:

Figure 28:


230
207
184
161
138
115
92
69
46
23
0
Production (tonne) (millions)
2015
2016
2017
2018
2019
2020
2021
2022
2023
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2032
2033
2034
Co2

Figure 29: